SCIENTIFIC INVESTIGATIONS OF ATMOSPHERIC PROCESSES

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Final Report

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October 6, 1987 - February 28, 1994

Program Director:

Donald J. Perkey, Ph.D.

Submitted to:

THE GEORGE C. MARSHALL SPACE FLIGHT CENTER

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FINAL ACTIVITIES REPORT

SCIENTIFIC INVESTIGATIONS OF ATMOSPHERIC PROCESSES

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This contract involved research in atmospheric dynamical and thermodynamical processes to develop procedures for combining generalized radiative transfer codes with dynamic atmospheric model codes to perform diagnostic analysis of atmospheric processes to gain better understanding of the evolution and development of mesoscale circulation systems and their precipitation structures, and to develop algorithms and software necessary to graphically display diagnostic sets on the MSFC McIDAS and EADS to facilitate scientific study and sensor capability evaluation.

Research Associates

Dr. William L. Crosson, Research Associate, was appointed January 28, 1991, to work in the Environmental Analysis Branch of ES44, of MSFC Earth Science and Applications Division to closely work with Dr. Steve Goodman and be involved in the following activities:

- Development and refinement of remote sensing algorithms in order to examine and retrieve the surface energy budget variables such as albedo, evapotranspiration, soil moisture, etc., over regional and global domains;
- Participate in field campaigns (such as CaPE, FIFE, GEWEX, STORM) to understand land-atmosphere interactions using ground-based, airplane and satellite data;
- Participate in studies of the water balance and exchanges between the earth and atmosphere over seasonal and interannual time scales to understand effects associated with the natural variability of the general circulation;
- Perform analyses of DMSP-OLS and SSM/I data in the context of the hydrologic cycle.

Dr. Crosson continued to perform research through the end of the contract, and a review describing his accomplishments are explained in this report.

Dr. Ravikumar Raghavan, Research Associate, began research on this contract June 8, 1992, and continued through the end of the contract. He performed research with Dr. Steve Goodman in the Environmental Analysis Branch to participate in radar data analysis for the CaPE Program, Tropical Ocean Global Atmosphere (TOGA) mission, and the Tropical Rainfall Measuring Mission (TRMM); and providing scientific support for the Lightning Imaging Sensor (LIS) research program and the application of radar rainfall estimates of hydrology. A review of his accomplishments is also included in this report.

Ms. Vada LaFontaine, Research Associate, worked on this contract from October 2, 1989, through November 30, 1990, to collaborate with Dr. Roy Spencer and Mr. Mike Goodman with implementation of the WETNET program and related meteorological data systems at MSFC.

Mr. Frank LaFontaine, Research Associate, worked from August 2, 1989, through December 31, 1990, with Dr. Roy Spencer in the satellite radiative transfer area with respect to microwave remote sensing. Specific areas of research were to assist with the development of applications of SSM/I, HIMMS and AMPR instruments for estimating precipitation rates and distributions from space, as well as other geophysical parameters.

Dr. Jorge Ramirez, Research Associate, worked October 16, 1989, through October 1, 1990, with Mr. Steve Goodman and Dr. Pete Robertson utilizing his expertise in the hydrological sciences to study precipitation processes and land/atmosphere interactions over space and time scales ranging from cloud scale to global scale.

Mr. Patrick Wright, Research Associate, worked from October 5, 1987, through March 8, 1993, to support the Remote Sensing Branch at MSFC in collaboration with scientific personnel addressing problems involving analysis of dual radar data.

Visiting Scientists

Dr. Ghassem Asrar, Senior Visiting Scientist, worked at NASA Headquarters in the Land Processes Branch coordinating research in NASA's Hydrology and Remote Sensing Science Program. Activities included oversight of EOS interdisciplinary investigations related to the ITIR facility instrument, and oversight of the NASA Land Data System and its interface with the Climate Data System and the EOSDIS.

Dr. Miriam Baltuck, Visiting Scientist, worked from April 10, 1989, through February 24, 1990, at NASA Headquarters in the Land Processes program, Geology Section, in particular to coordinate applications of Synthetic Aperture Radar technology.

Dr. Steve Goodman, Associate Scientist, worked December 12, 1987, through November 21, 1988, in support of Lightning Mapper definition and atmospheric electricity.

Dr. Robert Thomas, Senior Visiting Scientist, worked January 1, 1990, through February 7, 1992, at NASA Headquarters in the Earth Science and Applications Division coordinating with NASA in projects associated with polar oceans, sea ice, and terrestrial ice sheets that involve the analysis of satellite data and development of large scale models.

Dr. Ming-Ying Wei, Visiting Scientist, worked from April 2, 1990, through September 7, 1990, at NASA Headquarters with Dr. Stan Wilson, EOS Program Scientist, as an interface with the university atmospheric research community to identify their data and data access needs. His work contributed to development of specifications for EOS remote observations, sensors and related data systems.

Mr. Matt Smith, Visiting Scientist, worked from October 1, 1987, through January 18, 1991 as a computer applications specialist interfacing with NASA, USRA and university investigators on problems related to model implementation.

Summary of Accomplishments

Dr. William L. Crosson's activities on this contract have been directed toward modeling surface energy and hydrologic processes utilizing data collected during the Convection and Precipitation/Electrification Experiment (CaPE) held in east central Florida in July and August 1991. His objectives in this project were to establish and apply methodologies for the diagnosis of land and atmospheric waste budget components for the CaPE region (approximately 25000 km2). The underlying philosophy for this study, is that these techniques can be applied on scales consistent with GCIP activities such as the CART ARM experiment in Oklahoma and ultimately the Mississippi basin.

Specific activities to meet these objectives were as follow:

- Collecting and performing quality controll on data from a field program, as well as from many other agencies, and using these data to diagnose surface energy and water fluxes for the CaPE region. This included raingage measurements, satellite imagery (SPOT, AVHRR, GOES), soundings, surface energy flux measurements, radar data and geographical information. The surface flux and meteorological observations taken by MSFC (3 sites), Florida State University (2 sites) and the University of Georgia (2 sites) have been quality controlled by the respective institutions and made available to the public through MSFC. The precipitation data set, consisting of data from a multi-agency network of more than 200 gauges, has required extensive assimilation and quality control effort, but has become a valuable research tool. Investigators from several other institutions have requested the data set for their own studies.

- Building the Geographic Information System (GIS) database necessary for analysis of remotely-sensed data and for surface hydrologic and energy flux modeling. Soil types, topographic, hydrographic, basin boundary, and land cover data have been obtained and integrated on two GIS systems, the Image Station loaned by Intergraph and the PC-based AGIS package.

- Daily rainfall analyses from the WSI radar composites have been completed for an initial set of 14 daily periods. These have been used as the basis for comparisons of daily rainfall estimated by the raingage network versus rainfall derived from radar reflectivity's using published Z-R relationships. These comparisons indicate that the WSI radar composites overestimate rainfall over the CaPE region by an average of 70% for the 14-day period. Dr. Crosson, Dr. C. Duchon, who worked with USRA at NASA/MSFC as a consultant from the University of Oklahoma, and Dr. R. Raghavan have applied an alternative technique for estimating rainfall from the radar data. This approach is based on matching the probability distribution functions (pdf's) of radar reflectivity's and rain rates. The statistical analysis is based on 5 of the daily periods and applied to the other days as an independent test. The result of this work is a new "climatologically tuned" Z-R relationship that is appropriate for the WSI composite radar product within the Florida summer climate. The application of this Z-R relationship results in rainfall estimates which are relatively unbiased with respect to gauge amounts over large space and long time scales, although large discrepancies still exist

at the local scale. Preliminary comparisons have been made between rain volumes from gridded radar and analyzed raingage measurements integrated over various stream basins and stream discharge as measured by stream gauges. The purpose of this analysis is to gain an understanding of the response times involved for basins of different sizes. Ultimately, the stream discharge measurements will be used to validate model-diagnosed runoff.

Dr. Crosson derived surface reflectivities for each spectral band and calculated the Normalized Difference Vegetation Index (NDVI). Of interest for modeling activities is the spatial distribution of NDVI, and by inference vegetation properties such as leaf area index. He examined the distribution of NDVI for each land cover type and observed large differences in the mean and variance properties. This information will be used to define sub-grid scale variability of vegetation conditions for modeling purposes.

A modified version of the Biosphere-Atmosphere Transfer Scheme (BATS) has been tested using surface meteorological and energy flux measurements. The model has been applied using data from two of the CaPE surface flux sites; estimated heat and moisture fluxes are in good agreement with measured values. Model simulations have been performed for a composite data set derived from the 38 Portable Automated Mesonet (PAM) sites within our study area, with the aim of producing an initial estimate of aerial heat and moisture fluxes. Thirteen of the PAM stations measured incident short-wave radiation; four of these also collected reflected short-wave, emitted long wave and net radiation, and soil temperatures, variables need as model input. Model sensitivity to radiation input will be tested using a variety of methods for specifying solar and long wave fluxes using the point measurements. A number of questions can be addressed using this data. For example, what is the impact on model-diagnosed fluxes of spatially uniform radiative input, as compared with values measured at each site?

A more sophisticated modeling scheme for estimating aerial fluxes for the CaPE domain has been designed. This method incorporates BATS, geographic information (land cover classes and soil properties), and statistical distributions of surface properties (such as leaf area index, albedo and fractional vegetation cover) based on high-resolution remotely sensed data. Distributions of NDVI and spectral albedo have been derived from 20 m resolution SPOT imagery for each of the 18 land cover classes in the study area. The BATS model will be run at grid points for the CaPE domain; each grid cell will be treated as a mixture of land cover types. To add further realism to the model, the statistical distributions of surface properties within each land cover "patch" will be represented via a discrete probability density function inferred from the observed distributions of NDVI and albedo. Scale issues will be addressed with a series of model runs in which the resolution of remotely sensed data, used to establish the nature of surface variability, is degraded. Preliminary analyses have shown that degradation of SPOT data from 20 m up to 1 km resolution (simulating AVHRR footprints) results in large changes in both mean and variance of surface properties.

Dr. Crosson completed two 3-day courses taught by Intergraph: Modular GIS Environment System Nucleus and Image Station Imager. In addition to this training, a great deal of time was spent at MSFC gaining experience in GIS applications. Intergraph personnel supported this learning process.

Dr. Ravikumar Raghavan focused on several major objectives during the course of this contract. They are as follow:

- Preliminary analysis of data was obtained from the Convection and Precipitation Lightning Experiment (CaPE). An understanding of the relationships among the processes that lead to the electrification of clouds and the subsequent production of lightning is desired to better interpret global cloud measurements from future space missions such as the Tropical Rain Measuring Mission (TRMM) scheduled for launch in 1997. Detailed case studies examined the morphology of the co-evolving microphysical, electrical and kinematic properties of clouds using polarimetric radar measurements obtained by the National Center for Atmospheric Research (NCAR) CP-2 radar as well as the Advanced Microwave Precipitation Radiometer (AMPR) and the Lightning Instrument Package (LIP) measurements obtained during the NASA/ER2 flights during CaPE. Results were presented at the 26th International Conference on Radar Meteorology.

  Precipitation is a critical component of the hydrologic cycle, and an accurate estimate of rainfall over large areas and over long duration is important to hydrologic modeling and the correct apportioning of surface water into runoff, infiltration and evaporation. The large variability in the dynamics of precipitation makes it a difficult atmospheric variable to measure accurately with in situ pluviometric measurements. Radars offer a convenient way of observing precipitation at the required spatial and temporal scales. Case studies were performed to address the use of composite radar data obtained from WSR-57 radars to accurately estimate hourly/daily areamean rainfall and attempt to understand the underlying errors associated with this approach over Central Florida. Measurements from the NCAR CP-2 radar along with TRMM raingauge data were also used in the analyses. Results were presented at the 4th International Conference on Precipitation-Hydrological and Meteorological Aspects of Rainfall: Measurement and Predictability.

  The NASA/T-39 jet conducted several flights over precipitating clouds during CaPE and Tropical OceanGlobal Atmosphere/Coupled Ocean-Atmosphere Response Experiment (TOGA/COARE) experiments. The T-39 has on-board a dual-frequency (10GHz and 34.5GHz), dual-polarization 5o beam width radar viewing at near-radar incidence. Polarimetric radar measurements can be used to deduce the shape and orientation of non-spherical scatters in the Rayleigh regime. At Ka-band (34.5GHz) and for larger sized scatters, Mie scattering effects dominate by introducing oscillations in differential back scattering parameters. Albeit at this frequency deducing the mean shape of non-spherical scatters might be difficult, radar back scattering signatures like the linear depolarization ratio (LDR), differential propagation phase, and co-polar cross correlation coefficient provide information about the thermodynamic phase states of the scatters. Polarimetric radar modeling of hydrometers such as graupel and hail in various thermodynamic phase states(dry, spongy, wet) as well as rain at 35GHz were performed. The modeling results can be applied to understand and interpret LDR signatures recorded by airborne radars with nadir incidence such as those in CaPE and TOGA/COARE. Preliminary results were presented at the IEEE International Geoscience Remote Sensing Symposium (IGARSS '93). Vertically incident multiparameter radar data collected by the NCAR CP-2 radar from three

different campaigns, namely MIST (Microburst in Severe Thunderstorms), CINDE (Convective Initiation and Downburst Experiment) and CaPE were analyzed to study the application of LDR and copolar cross correlation coefficient HV(0), in locating the region of transition between rain and ice.

Identifying the regions of ice, melting ice, and rain is critical for profiling liquid water content (LWC) and rain-rates from spaceborne measurements such as the TRMM mission, and airborne measurements such as the X band radar on-board the NASA/DC-8 flights during TOGA/COARE. It was demonstrated that profiles of LDR and HV(0) obtained at vertical incidence can be successfully used to identify the phase transition of hydrometers, thereby demonstrating the potential of these techniques for spaceborne and airborne applications. The results were presented at the 26th International Conference on Radar Meteorology.

Dr. Raghavan demonstrated a technique for self-consistent assessment of the Area-Time Integral (ATI) method for rainfall estimates using multiparameter radar. This method computed ATI by thresholding on the reflectivity field Z. The rain volume was computed from fields other than Z, such as specific differential phase shift KDP or specific attenuation A. This procedure provides an excellent alternative to using the same Z field for both ATI and rain volume computations or using rain gauges whose estimates are affected by various uncertainties like advection, evaporation and most importantly inadequate sampling. Results were presented at the 4th International Conference on Precipitation-Hydrological and Meteorological Aspects of Rainfall: Measurement and Predictability.

- WSI-WetNet Marshall DAAC Operations: Algorithm design and Implementation for processing the real-time U.S. National Composite Radar Data are being received at the Distributed Active Archive Center (DAAC) via satellite link. The WSI radar data is received via satellite every 5 and 15 minutes and is being stored on the Marshall DAAC. The U.S. National radar composite image is then converted to a U.S. National Precipitation (Rainfall) image. This image is stored in the DAAC and has been made available as a browse product. The rainfall image will also be made available for distribution to the science community. Furthermore, the precipitation image will be made available on the LAN for viewing under the NASA Weather facility. Rigorous testing of the algorithm is being conducted in a modular model and final implementation is being incorporated.

Other related tasks Dr. Raghavan successfully accomplished:

- Developed software to peruse NEXRAD WSR 88-D radar data from Melborne, Florida. This allows for scientific evaluation and display of the data within the RDSS (Research Data Support System) software package for radar data analysis supported by NCAR.

- Procured and installed current versions of the NCAR graphics library and other related volumetric radar processing software on the SUN/SPARC workstation.
- Developed software for accessing the National WSI composite radar data for estimating daily rainfall. This product is to be broadcast daily under the WETNET project.

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Consulting and Workshops

The following consultants were retained by USRA to provide services. The consultants and their activities are listed below in alphabetical order.

Dr. William L. Boeck from Niagara University was appointed as a consultant to attend the Hydrologic Data Access and Archive Working Group (HDAAWG) meeting at Marshall Space Flight Center, June 29-30, 1993.

Mr. S. C. Brown was appointed November 1, 1989, through February 28, 1990, to revise and update the NASA Technical Memorandum (TM), Chapter 5 "Sea State" to make it more useful to NASA Space Shuttle and Air Force Alternate Launch System booster recovery and to include a review of current literature and study of new sea state publications. Wind speed and wave height duration and interval statistics were added for both Atlantic and Pacific Ocean recovery sites.

Mr. Ke-Sheng Cheng from the University of Village South in Gainesville, Florida, was authorized to visit NASA/MSFC to present a seminar in the Earth Sciences and Applications Division and hold discussions with scientific personnel, May 15-16, 1989.

Dr. Claude Duchon from NASA/MSFC was appointed to perform work with Dr. Steve Goodman involving research support for ES44 in the area of land-atmosphere interactions coupled to hydrology, May 16-31, 1992. Dr. Claude Duchon from the University of Oklahoma was appointed as a consultant to visit the surface energy budget sites associated with the Convection and Precipitation/Electrification (CaPE) experiment in east-central Florida in anticipation of analyzing data from these sites, August 1-5, 1991.

Dr. Christopher Grandt from Goddard Space Flight Center traveled to NASA/MSFC to hold discussions in the Earth Science and Applications Division with Dr. Steve

Goodman/Environmental Data and Information Systems Branch and Dr. Hugh Christian/Earth System Observing Branch on long-range detection of thunderstorms using remote sensing technologies. He also gave a presentation entitled, "Thunderstorm Climatology Derived from VLF-Sferics Measurements," July 11-13, 1993.

Mr. Stan Heckman from the Massachusetts Institute of Technology was authorized to travel to the Kennedy Space Center (KSC), Florida, to participate in the execution and analysis of data from the triggered lightning field measurement efforts, July 15, 1989, through September 30, 1989. Mr. Heckman also transported the Doppler Radar from Boston to KSC, November 1989.

Dr. Alex Huang from the University of North Carolina, participated in the 1988 Summer Visitors Program at NASA/MSFC, May 16, 1988, through July 22, 1988.

Dr. Huo-Jin Huang attended the 3rd AMS Conference on Satellite Meteorology and Oceanography to present papers on research results performed while working as a USRA intern, December 1987.

Mr. Greg Laslo provided programming assistance in the ED42 branch as a consultant, June 25-29, 1988.

Dr. Douglas K. Lilly from Florida State University, traveled to NASA/MSFC to give a presentation entitled, "Convective Storm Dynamics and Prediction," May 16, 1988.

Dr. Dave Mackerras from the University of Queensland in Brisbane, Australia, was appointed to design and construct a CGR3 instrument for the TOGA COARE experiment to gather data on intercloud and cloud-to-ground lightning, July 31, 1992.

Dr. Tom Marshall from the University of Mississippi was authorized to travel to Cocoa Beach, Florida, during the period July 15 through August 31, 1989, to support the 1989 Rocket Triggered Lightning Program at Kennedy Space Center.

Dr. John Marwitz from the University of Wyoming gave a presentation at the NASA/MSFC on his on-going research, January 1988.

Dr. Kent M. McGregor from Denton, Texas, was authorized to visit NASA/MSFC to present a seminar in the Earth Sciences and Applications Division, April 16-17, 1990.

Dr. Donald Perkey traveled from Pennsylvania to MSFC to consult with Drs. Pete Robertson and Mike Kalb concerning development use and results of LAMPS programs, February 1988.

Dr. Christopher T. Phelps from Kennedy Space Center was appointed as a consultant to USRA to participate in the execution and analysis of data from the triggered lightning field measurement efforts, summer 1989.

Dr. Jorge A. Ramirez from Colombia, South America was invited to visit NASA/MSFC to give a presentation and to hold discussions with the scientific personnel at MSFC regarding his research areas, May 7-8, 1989.

Dr. Donald Ryan from Northwestern State University of Louisiana was chosen as a Visiting Summer Fellow in the JOint VEnture (JOVE) Program at the Environmental Analysis Branch in the Earth Science and Applications Division, May 10 through July 19, 1989.

Dr. Murray Salby from the University of Colorado traveled to MSFC to give a presentation on his research activities, January 1988.

Dr. Verner Suomi from the University of Wisconsin, was authorized to travel to NASA/MSFC to participate in the "Distinguished Visitor/Seminar Series Program," to promote greater interaction between atmospheric scientists and fluid dynamists and the broader research community in areas relevant to NASA's programs, November 28-29, 1989.

Dr. Robert H. Thomas from Washington, DC, traveled to Mombetsu, Japan, to attend the Sea Ice Conference at the Sea Ice Research Laboratory, February 1-11, 1991.

Mr. Chris Zodrow from Dayton Beach, Florida, participated in the execution and analysis of data from the triggered lightning field measurement efforts at the Kennedy Space Center through the period July 15 to August 31, 1989.

Subcontract

A subcontract was awarded to the University of Arizona entitled, "A Review of Thunderstorm Electrical Processes and Their Effects on Aerospace Systems," for the period September 1, 1989 through April 30, 1990. The Principal Investigator for this subcontract was Dr. Charles D. Weidman.

During this effort the subcontractor's activities included the following tasks:

- Conduct a comprehensive review of the recent literature on thunderstorm dynamics, charge separation and thunderstorm fields including measurements from aircraft.
- Review recent experimental measurements of wide band lightning electromagnetic fields and measurements of lightning currents including spectral amplitude data and statistics on peak current derivatives. Review recent theoretical work which attempts to infer lightning current characteristics from remote field measurements.
- Summarize the current understanding of the mechanisms and characteristics of lightning triggered by small rockets and by aircraft.
- Discuss the hazards that may exist in charged clouds that may not be producing natural lightning and hazard forecasting.
- Review current test standards applicable to aerospace vehicle development.
- Recommend additional research and new or additional test procedures.

The subcontract final report remains on file at the USRA Corporate Drive office.

A subcontract was also awarded to the University of Colorado/National Snow and Ice Data Center under the direction of Dr. Greg R. Scharfen. The work was entitled, "The Analysis of U. S. Air Force Defense Meteorological Satellite Program Imagery for the Occurrence of Global Lightning for May and June of 1986 - 1989," to analyze the imagery obtained by the U.S. Air Force Defense Meteorological Satellite Program archive for the purpose of creating a climatology of global lightning signatures over the period of May through June 1986-1989. The resulting data set will be a digital record of the date, time and geographic location of each lightning signature apparent on the midnight passes of the DMSP satellites during this time period. The objectives were to:

- Analyze all available imagery from the midnight passes of USAF DMSO satellites from May - August, 1986-89 (approximately 10,000 - 11,000 images) for the identification of lightning signatures in the visible band imagery.

- Produce digital data set from the above analyses including the date, time, latitude and longitude of each of identifiable lightning signature.

Technical reports remain on file at the USRA Corporate Drive office.

4. Financial

Total Contract Value:	$1,620,876
Total Funded Value:	$1,599,503
Total Cumulative Costs and Fee:	$1,596,475

At physical ending of work on the contract, there was an unfunded value of $21,373. Of available funding, and estimated $3,028 is the residual through January 31, 1994.

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15. Supplementary Notes

16. Abstract This contract will involve research in atmospheric dynamical and thermodynamical processes and in other disciplines necessary to accomplish the following tasks: Develop procedures for combining generalized radiative transfer codes with dynamic atmospheric model codes, perform diagnostic analysis of atmospheric processes to gain a better understanding of the evolution and development of mesoscale circulation systems and their precipitation structures and to develop algorithms and software necessary to graphically display diagnostic sets on the MSFC McIDAS and EADS to facilitate scientific study and sensor capability evaluation.

Research activities during this reporting period are detailed in the attached technical reports.

17. Key Words (Suggested by Author(s))	18. Distribution Statement
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